# Dark Matter and TeV scale electroweak corrections

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In recent years, many interesting features have been discovered about the behaviour of radiative electroweak corrections at energies much higher than the weak symmetry breaking scale ( 100 GeV). It has become clear that electroweak radiative corrections at the Teraelettronvolt (TeV) scale, which is the energy scale relevant for present or near future accelerators, are much bigger than one could naïvely expect [1]. In fact, while at LEP energies ($\sim$ 100 GeV) electroweak corrections are parametrized by the weak coupling constant, $\frac{\alpha_W}{\pi} \lesssim 1\%$, a steady growth with energy makes them reach the 20$\div$30% level at the TeV scale. At higher energies, electro*weak* corrections keep on growing and become as big as the tree level values for the cross sections, thus making a perturbative treatment problematic. As one tries to understand the asymptotic behavior, i.e. how the cross sections depend on the typical energy of the process when the energy itself becomes much bigger than all particle's masses, two striking features emerge:

- the behavior of cross sections for energies much higher than the weak scale $M \sim 100$ GeV is related to the *infrared*, rather than the ultraviolet, structure of the Standard Model; $M$ plays the role of infrared cutoff [2].

- No "infrared safe" observable exists: even at the highest energies, all observables depend crucially on the low energy infrared cutoff $M$.

- Because o symmetry breaking, even fully inclusive observables feature uncancelled double logs of infrared origin.

Clearly, all of these studies are important for physics studies at colliders with center-of-mass energies at the TeV scale or more, like LHC or possible future lepton accelerators.

More recently, we have become aware that electroweak radiative corrections actually play a significant role in a radically different context: Dark Matter searches [7]. Indeed, EW radiative corrections are quantitavely more relevant than one could expect, as explained above.

Even bearing in mind that weak interactions are not so weak at the TeV scale, one might wonder whether such "strong" electroweak effects are relevant for measurements with uncertainties very far from the precision reachable by ground-based experiments at colliders. In this context, and in view of our ignorance about the physics responsible for DM cross sections, it might seem that even a $\mathcal{O}(30)\%$ relative effect should have a minor impact. This is by no means the case: including electroweak corrections has a huge impact on the measured energy spectra from DM decay/annihilation. There are two basic reasons for this rather surprising result.

- In the first place, since energy is conserved, but the total number of particles is not, because of electroweak radiation a small number of highly energetic particles is converted into a great number of low energy particles, thus enhancing the low energy ( $\lesssim 100$ GeV) part of the spectrum, which is the one currently accessible to $\bar{p}$ and $\bar{e}^+$ observations.

- Secondly, and perhaps more importantly: since all SM particles are charged under the $SU(2)_L \otimes \mathrm{U}(1)_Y$ group, including electroweak corrections opens new channels in the final states which otherwise would be forbidden if such corrections are neglected. In other words, since electroweak corrections link all SM particles, all stable particles will be present in the final spectrum, independently of the primary annihilation channel considered.

To illustrate these facts, consider for instance a heavy DM annihilation producing an electron-positron pair, see Fig. 1. Clearly, as long as one does not take into account weak interactions, only the leptonic channel is active and no antiproton is present in the final products. However, at very high energies there is a probability of order unity that the positron radiates a $Z$ or a $W$. While the spectrum of the hard positron is not much altered by virtual and real radiative corrections (see [8]), the $Z$ radiation opens the hadronic channel: for instance, antiprotons are produced in the $Z$ decay. Moreover, also a large number of pions are produced, which in turn decay to

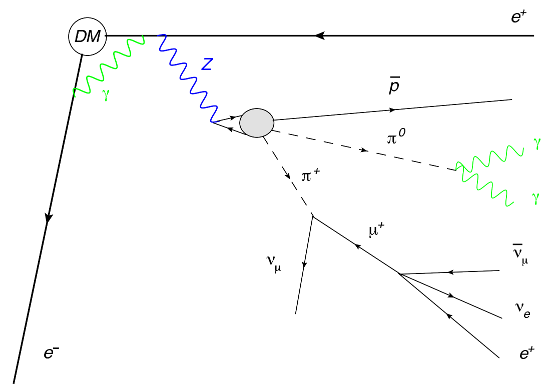


Figure 1. *DM annihilation/decay initially produces a hard positron-electron pair. The spectrum of the hard objects is altered by electroweak virtual corrections (green photon line) and real $Z$ emission. The $Z$ decays hadronically through a $q\bar{q}$ pair and produces a great number of much softer objects, among which an antiproton and two pions; the latter cascade decay to softer $\gamma$s and leptons.*

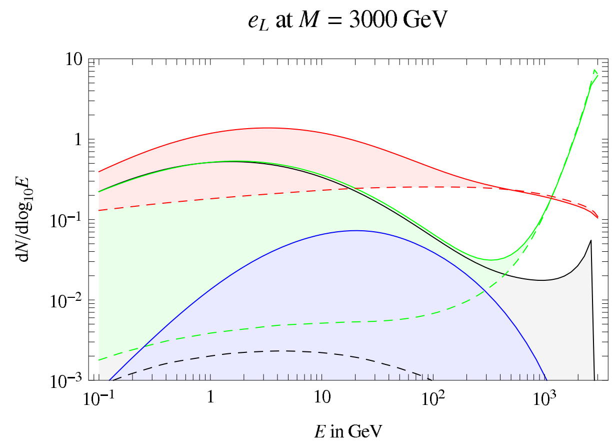


Figure 2. *Left, $Z$ from $W$ radiation: Comparison between our full result in the Minimal Dark Matter model (continuous yellow line), with its limit for $\epsilon \equiv M_W/M \to 0$ (blue dot dashed) and with our improved eikonal approximation (red dotted for the Sudakov parametrization and green dashed for the exact one). We show also the comparison with the naïve standard partonic approximation (black continuous line). Right, $\gamma$ from $W$ radiation: comparison between our full result (continuous red/blue line) with our improved splitting approximation in the exact parametrization (red/blue dashed) and the standard partonic one (red/blue dotted).*

photons ($\pi^0 \to \gamma\gamma$) and to low energy positrons (through the chain $\pi^+ \to \mu^+ + X \to e^+ + X$). At every step, energy is degraded. Because of the large multiplicity in the final states, the total $Z$ energy (already smaller than the hard $M$ scale) is distributed among a large number of objects, thus greatly enhancing the signal in the $(10-100)$ GeV region that is measured by present-day experiments, like PAMELA.

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